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NON-STEADY OSCILLATORY FLOW IN COARSE GRANULAR MATERIALS

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1 INTRODUCTION

Stationary and oscillatory flow through coarse granular materials have been investigated experimentally at Delft Hydraulics in their oscillating water tunnel with the objective of determining the coefficients of the extended Forchheimer equation. Cylinders, spheres and different types of rock have been tested for high Reynolds numbers. The extended Forchheimer equation coefficients will be derived during the ongoing analysis programme, and the dependency on different parameters, such as the porosity, gradation and stone shape and possibly also the Keulegan-Carpenter number will be examined. Further, for the non-stationary term, the virtual mass coefficient will be derived.

The present programme is part of the EC Marine Science and Technology research programme, MAST I, Contract 0032, G6-S, Coastal Structures, Project 1: 'Wave Action on and in Rubble Mound Structures'. Besides being of general interest, the present study of non-steady porous flow has relevance to two engineering problems:

- numerical modelling of wave action on and in rubble mound structures
- evaluation of scale effects in physical models of rubble mound structures

The tests were initiated due to the fact that existing results of non-steady flow in coarse materials were very scarce and did not show consistency. The main reason for the latter was the limitations of some of the applied experimental methods: the free fall U-tube technique, cf Hannoura and McCorquodale (1978) and Burcharth and Christensen (1991), by which oscillations cannot be produced. Only one set of data exists acquired in tests with oscillatory flow, see Smith (1991); however, with a limited range of parameter variations. The present tests were performed in the new oscillatory water tunnel at Delft Hydraulics. Due to the financial restrictions at the end of the G6-S programme, it was not possible to perform a comprehensive parametric study. However, tests were planned in order to get a good insight in some of the fundamental problems and to obtain approximate values of the main parameters, which characterize the flow resistance. Despite this, it is clear that a comprehensive parametric study is still needed.

The initial proposal for the test programme was done by O.H. Andersen and H.F. Burcharth. The final proposal was prepared by them together with J.W. van der Meer, G. Smith, Delft Hydraulics, M.R.A. van Gent and H. den Adel. The actual tests were performed by M.R.A. van Gent, O.H. Andersen and partly by G. Smith. Technical assistance was given by laboratory personal of Delft Hydraulics. The results of the experiments will be evaluated by the authors of this article.

2 EXPERIMENTAL SETUP AND PROCEDURE

The oscillating water tunnel at Delft Hydraulics was used for the tests. The length of the bottom section equals 15 m. A hydraulic system was applied to force the water through the stone samples at various amplitudes and periods.

A reduced cross-section of the flume equal to approximately 0.3x0.5 m^2 was used. This was obtained by inserting an additional bottom in the flume. The stone samples were mounted in the middle of the flume. All sample lengths equalled 0.8 m.

During the stationary tests, the water velocity outside the sample was recorded by a flowmeter and checked with laser doppler anemometer measurements. Under oscillatory flow, the water velocity was recorded by recording of the piston movement and checked by laser doppler.

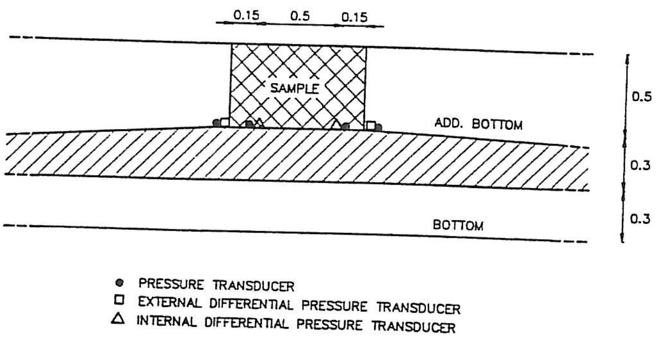

Fig. 1 Test section.

Inside the sample 0.15 m from each end, a pressure transducer and a pressure difference transducer were mounted. Just outside the sample, a pressure transducer and a pressure difference transducer were mounted.

The continuous transducer signals were recorded with a sampling frequency of 100 Hz and stored.

3 TEST MATERIALS

Below is given a summary of the materials tested in the new oscillating water tunnel.

Table 1 Test materials. d is the diameter. For the rock material, d is the equivalent spherical diameter. l/d is the aspect ratio and n is the porosity.

Matr. No	Matr. Desc.	d	d85/ d15	l/d	n
C1	Cyl. in quadratic packing	0.0515	1.00	1.0	0.792
C2	Cyl. in quadratic packing	0.0515	1.00	1.0	0.587
C3	Cyl. in quadratic packing	0.0515	1.00	1.0	0.324
S1	Spheres in cubic packing	0.046	1.00	1.0	0.476
R1	Irregular rock	0.076	1.27	1.9	0.442
R3	Semi round rock	0.0607	1.27	2.0	0.454
R4	Round rock	0.0606	1.26	2.2	0.393
R5	Irregular rock	0.0251	1.30	2.3	0.449
R8	Irregular rock	0.0385	1.74	2.0	0.388

Rock samples R1, R3 and R4 are identical to those applied in the stationary permeameter tests at Hydraulics Research, cf Williams (1992). Rock sample R8 is identical to the core material used in the breakwater tests at Franzius Institute, cf Ouméraci (1991).

4 PRELIMINARY ANALYSIS

During testing, it appeared that the piston displacement signals were not sinusoidal as intended causing some problems in the proceeding data analysis. This is probably due to the fact that the oscillating water tunnel is originally constructed for much larger amplitudes of motion than used during these tests. Another problem, which arose during testing, was that for the spheres and for the rock samples, a certain flow of water under the sample took place. The magnitude of this underflow has been measured with the laser doppler anemometer for a single rock sample. By assuming the square of the underflow velocity to vary proportionally with the gradient, all velocities are corrected for the underflow.

At the moment, the following preliminary coefficients for the stationary case have been found based on the internal pressure differential transducer:

$$I = \alpha \frac{(1-n)^2}{n^3} \frac{\nu}{gd^2} V + \beta \frac{1-n}{n^3} \frac{1}{gd} V|V|, \quad \nu = 1.14 \cdot 10^{-6} m^2/s$$

Matr. No	α	β
C1	28570	0.212
C2	9950	0.450
C3	3535	0.647
S1	1850	0.634
R1	~0	0.630
R3	~0	0.992
R4	~0	0.314
R5	2120	1.05
R8	3700	0.519

The β-coefficients appear to be significantly lower than expected from previous experiments. A comparison made for a single rock sample shows that if the external pressure differential transducer is used instead, the α and β values increase with a factor of approximately 1.5. For both the internal and external positions, the pressure difference derived from the absolute pressure transducers is 10-20 percent higher than found with the pressure differential transducers. This matter will be investigated further during the ongoing analyses.

A procedure for the analysis of the oscillatory case has been established. The β-coefficients will be derived from the points of time where the gradient as well as the velocity are at their maximum values. The inertia-term will be derived from the points of time where the velocity is almost zero. The actual analysis is awaiting the outcome of the analysis of the stationary case.

5 PRELIMINARY CONCLUSIONS

Experiments with stationary and oscillatory flow through coarse granular materials have been carried out with the objective of determining the coefficients of the extended Forchheimer equation. The analyses are being carried out at the moment. The stationary β-coefficients appear to be lower than expected. This will be investigated further.

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